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MEMORANDUM

From: Bill Jemison
To: Dr. Daniel Tam, ONR
Date: 1/31/2012

Subject: Progress Report 005–
Chaotic LIDAR for Naval Applications: FY12 Quarterly Progress Report (10/1/2011– 12/30/2011)

This document provides a progress report on the project "Chaotic LIDAR for Naval Applications" covering the period of 10/1/2011– 12/30/2011.

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FY12 Q1 Progress Report: Chaotic LIDAR for Naval Applications

This document contains a **Progress Summary for FY12 Q1**

Progress is reported towards the development of a wideband 536 nm fiber laser and signal processing techniques to support lidar system experiments.

Wideband Laser Development

Two fiber ring lasers have been developed to date. Both were described in Progress Report 004; one is a 1550 nm source based on erbium (Er) doped fiber which was constructed as a proof-of-concept laser. The other is a source based on ytterbium (Yb) doped fiber which will be frequency doubled to the blue-green wavelength required for underwater experiments. At the end of last period the Yb fiber laser had been constructed but not fully characterized. Both lasers have long passive fibers inserted into their resonator cavities, allowing many modes to lase simultaneously. These multiple modes fill a wide bandwidth power density spectrum (PSD), providing a noise-like temporal signal that is excellent for autocorrelation-based ranging. These modes couple chaotically, and their amplitudes are thus constantly fluctuating.

A photograph of the Yb fiber laser is shown in Figure 1.

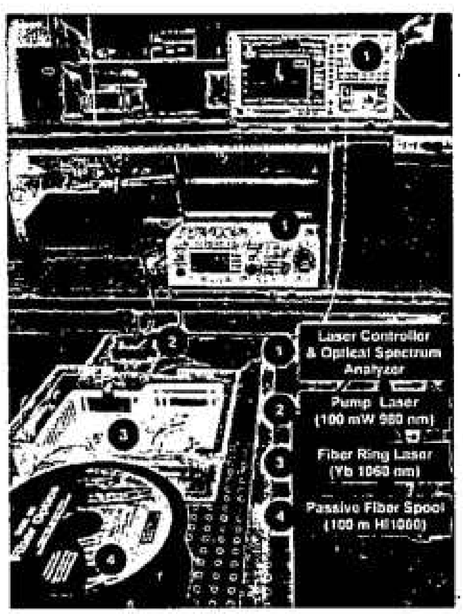

Figure 1. Photograph of the Yb fiber laser

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Characterization of the Yb fiber laser has been performed this period. The optical signal spectrum is shown below in Figure 2a. Figure 2b shows the laser produces a wide RF spectrum as desired. It is noted; however, that the spectrum is not as flat as obtained in the Er laser. This is most likely due to the narrower gain bandwith of Yb compared to Er, but is being investigated more fully.

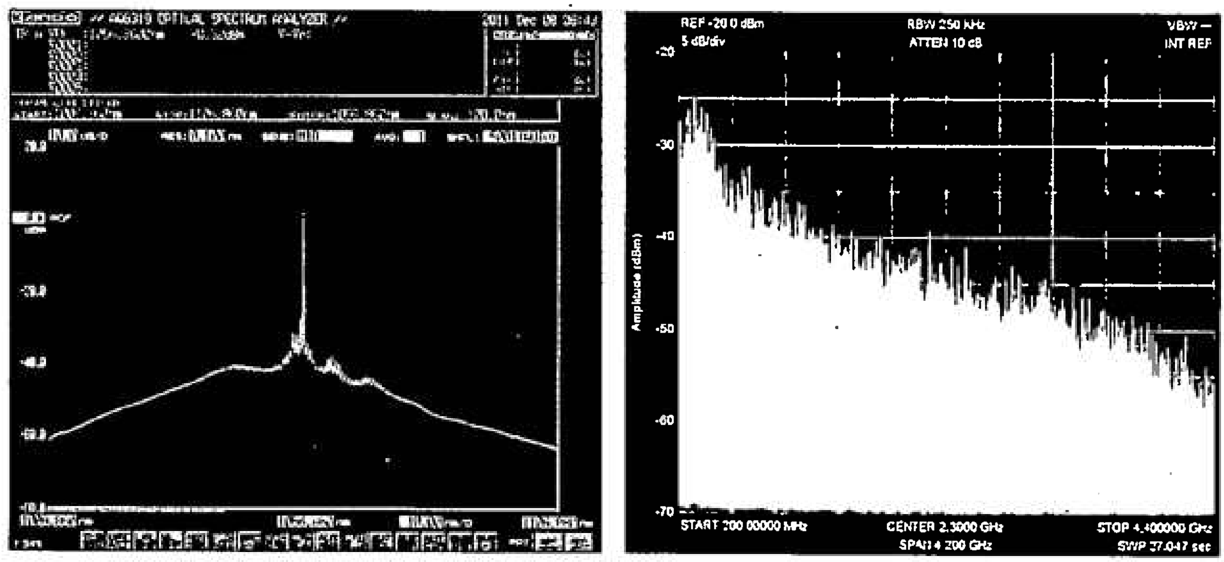

Figure 2. Left Plot: Optical spectrum of the fiber ring laser showing the output wavelength at 1054 nm (measured at ~1 mW output power, noting that there is a 5-10 dB loss due to fiber diameter mismatch between the fiber ring laser (~6 um MFD) and the analyzer (~9 um MFD)).
Right Plot: RF spectrum of the photo-detected output of the 1071 nm fiber ring laser. The broad RF bandwidth shows many simultaneously lasing modes.

We also have further investigated the dynamic behavior of the modes that make up the laser output. The dynamic behavior of individual longitudinal mode amplitudes was measured in order to quantify the variation in mode amplitudes. A model of a multimode laser output was then constructed where the modes were allowed to vary randomly with mode amplitude variations determined by the experimental data. An autocorrelation of this laser output using 500 modes was computed and compared to an autocorrelation that was computed from a simulated laser output with 500 equal amplitude modes. As shown in Figure 3, only minor changes in the autocorrelation function are observed in the presence of dynamic mode fluctuation. While the absolute peak amplitude is decreased, the peak-to-sidelobe ratio (PSLR) is not affected, and the peak width remains the same. This result gives us confidence that the dynamic mode behavior observed in these fiber ring lasers will not degrade the performance of autocorrelation-based signal processing for ranging.

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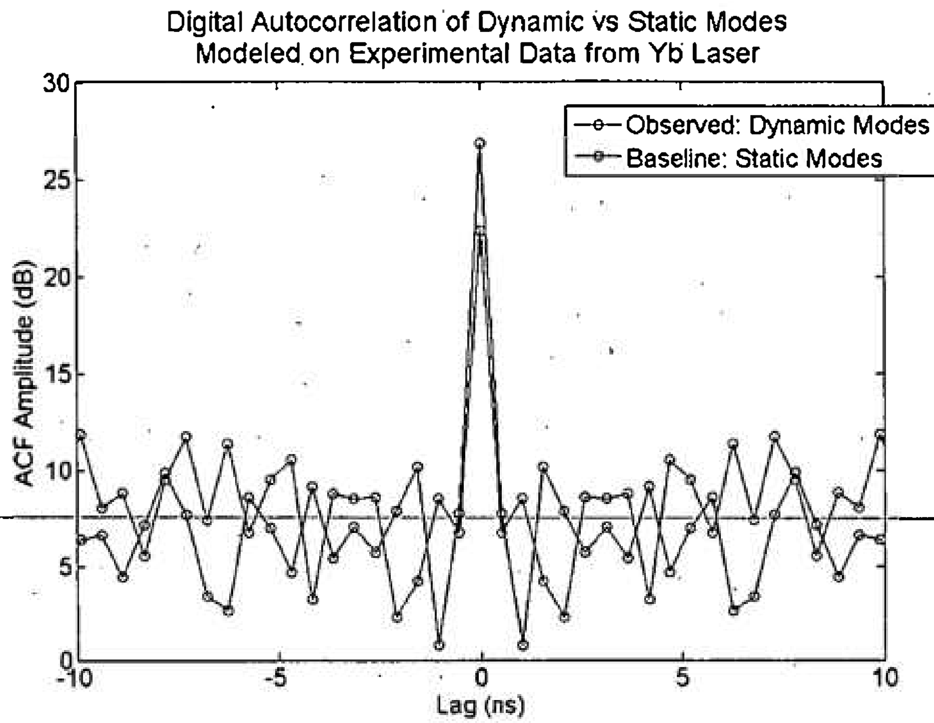

Figure 3. The quality of the autocorrelation of a simulated fiber laser with fluctuating modes is seen to be equal to the hypothetical baseline case of a laser with equal non-varying modes. While the peak amplitude is decreased, peak sidelobe ration is not adversely affected.

In order to effectively use the wide bandwidth Yb source for underwater lidar, its wavelength must be converted to one that efficiently propagates in water. The 1071 nm Yb fiber laser can be doubled to 536 nm, which is known to be near-optimal for turbid water transmission. While this 536 nm optical signal is considered optimal for underwater propagation, it would still face severe losses from absorption and scattering, as well as some losses in the signal processing hardware. Therefore, our frequency doubled laser must have adequate power to support system experiments. We are targeting an output power of 0.1 - 0.5 Watts. This would require 30dB of amplification prior to frequency doubling. Efficient frequency doubling methodologies have been demonstrated using second-harmonic generating crystals. We are investigating both commercial and in-house doubling solutions.

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System Level Experiments in Signal Processing

We are currently investigating two signal autocorrelation-based signal processing techniques. The first is an analog approach based on a coherent noise detection (CND) approach that was originally proposed for noise radar. We are also investigating a digital signal processing (DSP) approach based on a software defined radio architecture.

CND Receiver

The block diagram of the analog CND receiver is shown in Figure 4.

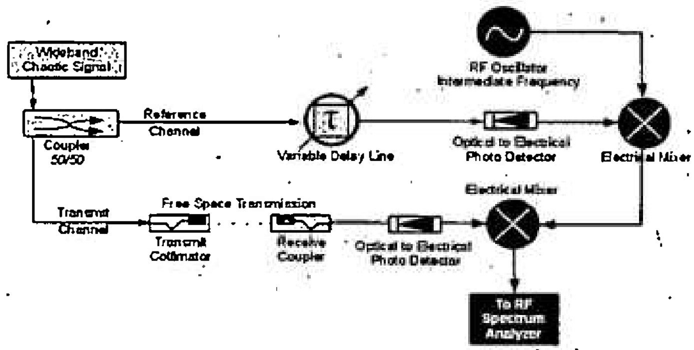

Figure 4. The coherent noise detection (CND) circuit splits an optical source into two paths: reference and probe. The probe signal crosses a delay, as if it were sent to a target, before returning and being electrically cross-correlated with the reference signal. Thus the delay length (target distance) is known.

We have constructed the receiver and have taken measurement data using a sinusoidally intensity modulated laser. A photograph of the CND receiver is shown in Figure 5.

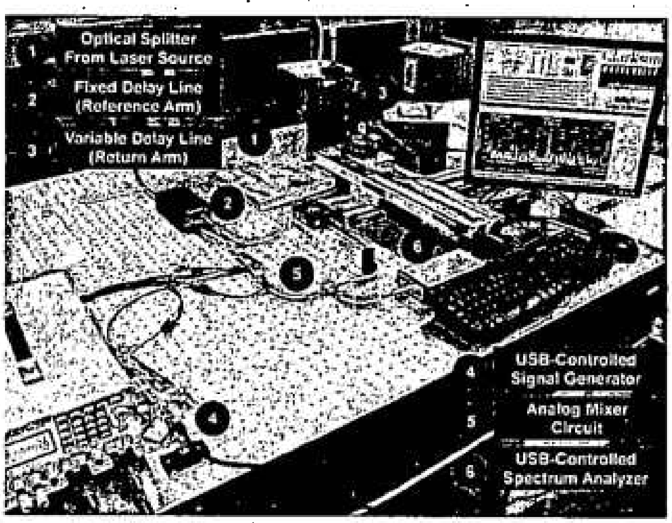

Figure 5. Photograph of the coherent noise detection receiver

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This circuit accepts an optical signal as an input, and generates the autocorrelation of the input signal as an output. The circuit is usable with any optical transmission path, whether fiber, air, or water; preliminary proof-of-concept tests have been conducted in air. The output is a DC signal whose amplitude varies with transmission path delay, as would the autocorrelation function.

For our initial measurements we used a sinusoidally modulated laser signal rather than the wideband fiber laser signal in order to simplify the receive path calibration. Figure 6 shows a comparison of the experimental autocorrelation with the theoretically expected autocorrelation. Both results are in good agreement. We are currently working on measurements of the Yb fiber laser. Performing autocorrelation with the fiber ring laser is slightly more difficult since the autocorrelation function of its flat spectrum is a sharp, non-periodic peak, so path matching must be precise. Amplification is also necessary for the fiber ring laser to drive the CND circuit.

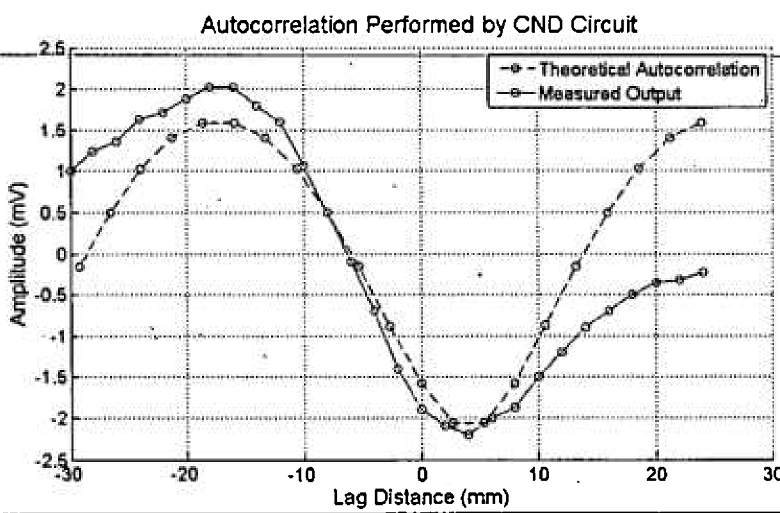

Figure 6. The analog CND circuit produces an autocorrelation of the input periodic signal. The actual output matches the theoretical autocorrelation as shown.

Software Defined Radio Receiver

We are also exploring a digital signal processing (DSP) based implementation using software defined radio receivers. A software defined radio (SDR) was used to digitize the output of the signal obtained from the Yb fiber laser. The data was used to generate an autocorrelation calculated from 4.4GHz of spectral data obtained by sweeping the software defined radio center frequency from 10 MHz to 4.4 GHz. Only amplitude data was used in the autocorrelation since the phase of the SDR is not coherent with each frequency step. The result is shown in Figure 7. We are currently looking at alternative SDR architectures that would allow us to maintain phase coherency during the data collection.

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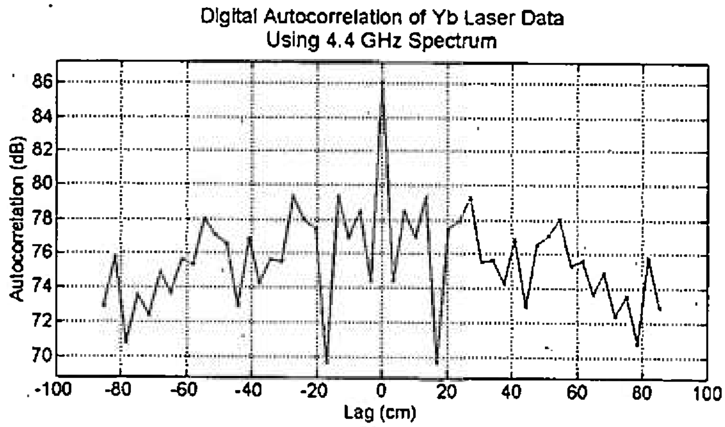

Figure 7. The analog CND circuit produces an autocorrelation of the input periodic signal. The actual output matches the theoretical autocorrelation as shown.

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